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Feasibility of husk-fuelled steam engines as prime mover of grid-connected generators under the Thai very small renewable energy power producer (VSPP) program

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Abstract

Rice husk generated as a by-product of rice mill processes can be utilized as an energy source for husk-fuelled rice mills. The economic evaluation of the investment of husk-fuelled steam engine rice mills, which generate mechanical energy for the direct driving of milling equipments, has previously been presented in literature. It was reported that for some particular conditions of rice mill, the investment of husk-fuelled steam engine as energy-saving technology is financially feasible. Since May 2002, electricity distributors in Thailand have allowed renewable energy producers up to 1 MW to connect their generators to the grid in order to sell surplus electricity to the grid. This arrangement creates more income opportunities for husk-fuelled steam engine owners to generate not only mechanical power for rice milling processes, but also surplus electricity for feeding onto the grid. The objective of this study is to investigate the financial feasibility of the investment in a husk-fuelled steam engine system which drives grid-connected electrical generators, reduces rice mill demand and electricity and sells surplus electricity to the grid. The technical and economic data for rice mill sizes 35, 45, 60, 95 and 120 t/d presented in this study show that the husk-fuelled steam engine system with grid-connected generators improves the economic performance of applying the system solely for the largest 120 t/d rice mills. However, the conventional husk-fuelled steam engine without electric generator gives a better economic performance of the rice mills sizes from 45 to 95 t/d.

Keywords: Rice husk; Rice mill; Steam engine; Feasibility study; Biomass energy

1. Introduction

Rice farming is the largest agricultural sector in Thailand, both in terms of cropped harvested areas and its percent of the GDP. The paddy harvested area covered 48.3% of agricultural area in Thailand in 2001 and its share of GDP of the agricultural sector was 23.4% in 2001 [1]. The annual rice paddy production is approximately 20 million tons. Rice husk is one of the by-products of the rice milling process. The annual production of rice husk is approximately 4.6 million tons [2]. Rice husk can be burned and heat of combustion used in the rice mills. However, only 50.7% of the rice husk produced at the mills is currently being used as fuel for energy production [3]. The use of husk in other industries rather than rice processing, involves the handling and transportation of this low bulk density (112–144 kg/m^3) by-product. By using rice husk at the rice mills for energy generation, instead of transporting the rice husk elsewhere, reduces capital costs of transport and disposal.

Rice milling is the process by which husk and bran are removed from rough rice in the production of white rice. Some sources of power generation are required in the husking, polishing, whitening and separating processes. Traditionally, there are two popular types of rice mill in Thailand: (1) the electrical rice mill and (2) the mechanical husk-fuelled rice mill. In the electrical rice mill, all equipment is powered by electricity. In the husk-fuelled rice mill, heat of combustion of rice husk converts water into steam. In the steam engine, the thermal energy of the steam is converted into mechanical power and the generated mechanical power is transmitted to drive the milling equipment directly without converting it into electrical energy.

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Nomenclature

CF_n	cash flow year *n*th, THB
$C_{f,n}$	fuel cost year *n*th, THB yr^{-1}
$C_{l,n}$	labor cost year *n*th, THB yr^{-1}
$C_{OM,n}$	operation and maintenance cost year *n*th, THB yr^{-1}
HPR	Husk to paddy ratio, decimal
D	demand saving, kW
e_e	rice mill specific electricity consumption, kW h t^{-1}
E	mill electricity consumption, kW h yr^{-1}
E_S	energy saving, kW h yr^{-1}
E_E	feed in electricity to the grid, kW h yr^{-1}
E_G	generated electricity, kW h yr^{-1}
f	inflation rate, decimal
f_e	energy charge inflation rate, decimal
G	generator capacity, kW
H	operation hour, h yr^{-1}
h_{fg}	vaporization enthalpy of water at 25 °C, kW h kg^{-1}
IN_n	total income year *n*th, THB yr^{-1}
INV	investment in husk-fuelled steam engine generator, THB
ΔL_s	number of extra workers for husk-fuelled steam engine system, person
LHV_d	lower heating value dry basis, kW h t^{-1}
LHV_w	lower heating value wet basis, kW h t^{-1}
MC_w	moisture content wet basis, decimal
m_f	fuel consumption, t yr^{-1}
$m_{f,avai}$	available rice husk, t yr^{-1}
N	economic project life time, yr
NPV	net present value, THB
OUT_n	total expenditure year *n*th, THB yr^{-1}
P	annual amount of paddy milled in the mill, t yr^{-1}
PCF	plant capacity factor, decimal
p_{ed}	price of electricity demand, THB kW^{-1} $month^{-1}$
$p_{ee,n}$	mill buying price of electric energy year *n*th, THB kW^{-1} h^{-1}
$p_{ex,n}$	feed in electricity tariff year *n*th, THB kW^{-1} h^{-1}
$p_{h,n}$	price of rice husk year *n*th, THB t^{-1}
$p_{l,n}$	wage rate year *n*th, THB man-day^{-1}
$p_{om,n}$	operation and maintenance factor year *n*th, THB kW^{-1} h^{-1}
Q	heat demand for steam engine system, kW h yr^{-1}
r	economic discount rate, decimal
S	rice mill capacity, t/d
THB	Thai currency, Thai Baht
u	mill use factor, decimal
η_{th}	energy conversion efficiency, decimal

As presented in the data collected by Sookkumnerd et al. [4], the mechanical energy generated by husk-fuelled steam engines reduces the specific mill demand from 2.7 to 1.64 kW/(t/d) and reduces the specific electricity consumption of the mill from 43.75 kW h t^{-1} to 22.75 kW h t^{-1}. The financial viabilities of the mechanical husk-fuelled steam engines as an energy-saving technology in Thai rice mills are determined. It was found that for rice mills larger than 45 t/d, it is financially feasible and profitable to invest in mechanical rice fuelled steam engines as an energy-saving technology for the rice mill. Moreover, the sustainable energy generation from a local biomass, raw material fuel source is both market-based competitive and environmentally friendly for the region.

Since May 2002, electricity distributors in Thailand have allowed renewable energy producers up to 1 MW to connect their generators to the grid. Thus, the renewable energy producers receive an attractive retail tariff rate for the electricity fed onto the grid. According to Sookkumnerd et al. [4], the husk-fuelled rice mill consumes only 52.3% of the generated husk from the rice milling process. However, by allowing the small generators to connect to the grid, additional income opportunities are created for the husk-fuelled steam engine owners. They are able to generate not only mechanical power for rice processing, but also electricity for feeding into the grid. Moreover, a larger amount of husk than 52.3% can be converted for energy generation purposes. When steam engines are used with a grid-connected generator, an alternative design concept of steam engine rice mill can be made. Instead of transmitting mechanical energy to the milling equipment, the steam engine is connected to an electricity generator which supplies the electrical power to the rice mill and also feeds surplus electricity to the utility grid.

By implementing this far more economically viable process, the operation of the rice mill becomes independent from the operation of the steam engine, along with gaining the advantage of a better control of the rice milling process itself. The benefit of using biomass energy not only encompasses the financial benefits to the investor, but also the public benefits, such as lower economic import costs, more positive contribution to Thailand's GDP, the creation of employment, greater contribution to public revenues and taxes, a significant contribution to the rural economy, a strong contribution to technology development, and environmental improvements [5].

The objective of this study was to present a systematic methodology for the financial feasibility evaluations of husk-fuelled steam engines as the prime movers of grid-connected generators under the Thai Very Small Renewable Energy Power Producer (VSPP) program. The results obtained from this study were comparable to the financial feasibility evaluations of the mechanical energy-generating husk-fuelled rice mill presented in earlier studies.

2. The Very Small Renewable Energy Power Producer (VSPP) program

In May 2002, Thailand's Cabinet passed new regulations to allow the very small renewable energy power producers of solar, wind, micro-hydroelectricity, biomass or biogas generators up to 1 MW per installation to connect to the grid. According to "Regulations for the purchase of power from Very Small Renewable Energy Power Producer (VSPP)/October 2004

[6]'', the VSPPs who generate less electricity than they consume in a monthly period will receive the retail tariff rate for electricity fed into the grid. For net excess production, the average wholesale tariff rate, which is the cost of generation and transmission, is offered to the VSPP. Those rates are very attractive for the power producers.

The example of a VSPP tariff calculations for Medium General Service customers[1] (12–33 kV) are presented in Tables 1 and 2. Consider Table 1 as the example of a VSPP tariff calculation for the producer who generates less electricity than s/he consumes. Then note Table 2 which presents the example of a VSPP tariff calculation for a producer who generates more electricity than s/he consumes.

The ''Regulations for the purchase of power from very small renewable energy power producers [6]'' clarify the permitted fuel types, application and connection procedures, expense for each party, technical requirements for generators to connect to the grid, tariffs and billing procedures. The technical requirements cover required protective relay, communication and criteria for synchronization, which encompass acceptable voltage levels, frequency and power factors. Photovoltaic (PV) systems using grid inter-tied inverters and small rotating generators, either synchronous or induction generators, are then allowed to connect to the utility grid [7].

The result of passing ''Regulations for the purchase of power from very small renewable energy power producers'' is successful progress in the promotion of renewable energy in Thailand. The new program is also known as ''net metering'' since it allows on-site energy generation. As of April 2005, 87 VSPP applications have been approved. Most of them are small rooftop solar cells (under 5 kW). There are three producers using rice husk as fuel and their total capacity is 2200 kW. The status of approved VSPP applicants is presented in Table 3.

The feasibility of generating electricity by steam engines under the VSPP arrangement was also emphasized by Greacen [9] who states that steam turbines and steam engines fired by agricultural residues, such as rice husk or palm husk, are also likely to be economically viable in many situations. In some cases, steam engines that powered rice mills half a century ago are now being refurbished to produce electricity under net metering arrangements.

3. Methodology

To evaluate the economic performance of husk-fuelled steam engines as prime movers of grid-connected generators throughout the entire project life, an economic model was developed. The model allowed the authors to determine the internal rate of return (IRR), for investments in husk-fuelled steam engines and electric generator systems. By this objective, IRR is not IRR of the whole rice mill investment, but only of the IRR as an additional investment in the husk-fuelled steam engine system under a VSPP arrangement.

The model begins with an analysis of the fuel availability. The husk to paddy ratio (HRP) is used for estimating the fuel availability. The annual available rice husk is evaluated by an equivalency noted as Eq. (1). The maximum fuel consumption (m_f) is limited to 95% of available rice husk ($m_{f,avai}$). The lower heating value of rice husk on a wet basis is determined by Eq. (2):

$$m_{f,avai} = 365Su(\text{HRP}) \tag{1}$$

$$\text{LHV}_w = (1 - \text{MC}_w)\text{LHV}_d - h_{fg}\text{MC}_w \tag{2}$$

The plant capacity factor of the husk-fuelled steam engine power plant depends on the availability of rice husk. However, the maximum plant capacity factor is limited to 85% and the maximum amount of rice husk which can be used as fuel is 95% of the available rice husk, as mentioned above. Eq. (3) is used in calculating the plant capacity factor, as described below.

$$\begin{aligned} \text{PCF} &= 0.85 & &\text{if } \frac{0.95m_f\text{LHV}_w\eta_{th}}{8760G} > 0.85 \\ &= \frac{0.95m_f\text{LHV}_w\eta_{th}}{8760G} & &\text{if } \frac{0.95m_f\text{LHV}_w\eta_{th}}{8760G} < 0.85 \end{aligned} \tag{3}$$

The total annual income derives from demand saving (D), saving of electrical energy, (E_s) and selling the surplus electricity to the grid (E_E). The reduction in electricity demand depends on the generator capacity (G) and the plant capacity factor (PCF). In this study, it was assumed that demand saving derives from a product of multiplication between G and half of PCF, as presented by Eq. (4).

$$D = 0.5\text{PCF}(G) \tag{4}$$

Mill use factor (u) was defined as the ratio between the actual amount of paddy processed in the mill, P (t yr^{-1}), and the maximum potential amount of paddy milled, as presented by Eq. (5). The mill energy consumption (E) depends on the specific mill electricity consumption (e_e) and the amount of milled paddy, which depends on the mill capacity (S) and the mill use factor, u, as presented by Eq. (6).

$$u = \frac{P}{365S} \tag{5}$$

$$E = 365Se_eu \tag{6}$$

The annual electricity generation (E_G), the annual electricity saving (E_s) and the annual electricity sale (E_E) can be found out from Eqs. (7)–(9), respectively.

$$E_G = 8760G(\text{PCF}) \tag{7}$$

$$\begin{aligned} E_S &= E & &\text{if } E_G > E \\ &= E_G & &\text{if } E_G < E \end{aligned} \tag{8}$$

$$\begin{aligned} E_E &= 0 & &\text{if } E_G < E \\ &= E_G - E & &\text{if } E_G > E \end{aligned} \tag{9}$$

[1] Medium General Service customers are the customers whose 15-minute peak demand is between 30–1000 kW and their 3-month average electricity consumption is less than 250,000 kW h/month.

Table 1
An example of VSPP tariff calculation for the producer who generates less electricity than he consumes

	No. of kW h	Energy charge	Total energy charge (Baht)	kW	kVar	Demand (B/kW)	PF (/kVar)	Ft	Total electricity charge (Baht)	VAT (7%)	Grand total
Consumption	20,000	1.7034	34,068	30	25	196.26	14.02	0.2612	45,270	3169	48,438
Generation	10,000	1.7034	17,034					0.2612	19,646	1375	21,021
								VSSP pays VAT		1793.65	

Source; EPPO [8].

The terms p_{ed} (THB kW^{-1} month^{-1}), p_{ee} (THB kW^{-1} h^{-1}) and p_{ex} (THB kW^{-1} h^{-1}) are the purchase prices of electricity demand and energy and the feed-in tariff, respectively.

The annual cash flow (CF_n) is the difference between the income (IN_n) and the expenditure (OUT_n). The incomes and expenditures must be calculated every year throughout the project life. To include the effect of inflation rate, the terms $p_{ee,n}$, $p_{h,n}$, $p_{om,n}$ and $p_{l,n}$ varies annually according to the inflation rate (f). The subscript n indicates nth year of the project.

$$\mathrm{CF}_n = \mathrm{IN}_n - \mathrm{OUT}_n \tag{10}$$

From Eq. (4), Eqs. (7)–(9), income equation can be developed, as expressed by Eq. (11).

$$\mathrm{IN}_n = 12\mathrm{D}p_{ed} + E_s p_{ee,n} + E_G p_{ex,n} \tag{11}$$

The annual expenditure (OUT_n) in Eq. (12), comprises three components, namely the fuel costs ($C_{f,n}$) due to the loss of opportunity to sell husk, additional operation and maintenance costs ($C_{OM,n}$) and additional labor costs ($C_{l,n}$) given by Eqs. (13)–(20). The annual operation hour (H) relates to the PCF. However, the plants are not always running at full capacity (G). When taking this into account, the operation hour factor is estimated by the plant capacity factor (PCF) plus 0.15, as presented by Eq. (19).

$$\mathrm{OUT}_n = C_{f,n} + C_{OM,n} + C_{l,n} \tag{12}$$

$$C_{f,n} = m_f p_{h,n} \tag{13}$$

$$m_f = \frac{Q}{\mathrm{LHV_w}} = \frac{E_G}{\eta_{th}\mathrm{LHV_w}} \tag{14}$$

$$C_{f,n} = \frac{8760(\mathrm{PCF})G[p_h(1+f)^n]}{\eta_{th}\mathrm{LHV_w}} \tag{15}$$

$$C_{OM,n} = \mathrm{E}p_{om,n} \tag{16}$$

$$C_{OM,n} = 8760(\mathrm{PCF})G[p_{om}(1+f)^n] \tag{17}$$

$$C_{l,n} = H\Delta L\frac{p_{l,n}}{8} \tag{18}$$

$$H = 8760(\mathrm{PCF}+0.15) \tag{19}$$

$$C_{l,n} = \frac{8760(\mathrm{PCF}+0.15)\Delta L p_l(1+f)^n}{8} \tag{20}$$

The objective of determining IRRs in this analysis is to compare the project IRRs with the bank interest rate. By this objective, all investment is considered as a present value at the beginning of the project and the term of loan-payment and interest were not included in the determining of IRRs. The cash flow expression of Eq. (21) is formulated by substituting Eq. (10) for Eqs. (12)–(20). The expression of net present value (NPV) as a function of annual cash flow (CF_n) and the difference of steam engine rice mill investment and electrical rice mill investment (INV) are given in Eq. (22).

$$\begin{aligned} CF_n = {} & \left[12\mathrm{D}p_{ed} + E_s p_{ee} u(1+f_e)^n + E_G p_{ex,n}(1+f_e)^n\right] \\ & - \frac{8760(\mathrm{PCF})G[p_h(1+f)^n]}{\eta_{th}\mathrm{LHV_w}} \\ & - 8760(\mathrm{PCF})G[p_{om}(1+f)^n] \\ & - \frac{8760(\mathrm{PCF}+0.15)\Delta L p_l(1+f)^n}{8} \end{aligned} \tag{21}$$

$$\mathrm{NPV} = -(\mathrm{INV}) + \sum_{n=1}^{N}\frac{\mathrm{CF}_n}{(1+r)^n} \tag{22}$$

when $\mathrm{NPV}=0$, the discount rate, r is known as the internal rate of return, IRR. Eq. (22) can be rearranged as:

$$\mathrm{INV} = \sum_{n=1}^{N}\frac{\mathrm{CF}_n}{(1+\mathrm{IRR})^n} \tag{23}$$

Table 2
An example of VSPP tariff calculation for the producer who generates more electricity than he consumes

	No. of kW h	Energy charge	Total energy charge (Baht)	kW	kVar	Demand (B/kW)	PF (/kVar)	Ft	Total electricity charge (Baht)	VAT (7%)	Grand total
Consumption	10,000	1.7034	17,034	30	25	196.26	14.02	0.2612	25,624	1794	27,417
Generation	10,000	1.7034	17,034					0.2612	19,646	1375	21,021
Generation	10,000	1.7853	17,853					0.2792	20,645	1445	22,090
								VSPP gets VAT refund		−1027	

Source; EPPO [8].

Table 3
Status of approved VSPP applicants (April, 2005) [8]

Fuel	No. of applicant	Max. capacity to grid (kW)
1. Solar cell	66	62.5
2. Wood Chips	1	400
3. Paddy Husk	3	2200
4. Biogas	13	3045
5. Waste	2	1950
6. Palm Shell	2	1500
Total	87	9157.5

$$\mathrm{INV}=\sum_{n=1}^{N}\left\{\frac{1}{(1+\mathrm{IRR})^{n}}\left\{\left[12\mathrm{Dp}_{\mathrm{ed}}+E_{\mathrm{s}}p_{\mathrm{ee}}u(1+f_{\mathrm{e}})^{n}+E_{\mathrm{G}}p_{\mathrm{ex},n}(1+f_{\mathrm{e}})^{n}\right]-\frac{8760(\mathrm{PCF})G[p_{\mathrm{h}}(1+f)^{n}]}{\eta_{\mathrm{th}}\mathrm{LHV}_{\mathrm{w}}}-8760(\mathrm{PCF})G[p_{\mathrm{om}}(1+f)^{n}]-\frac{8760(\mathrm{PCF}+0.15)\Delta L p_{\mathrm{l}}(1+f)^{n}}{8}\right\}\right\} \tag{24}$$

To solve the complicated Eq. (24), an Excel spreadsheet, computer-based model was developed, comprised of four spreadsheets. One of those spreadsheets is presented in Fig. 1.

4. System descriptions

The conceptual design of the husk-fuelled steam engine developed for driving grid-connected generators is different from the design of the conventional husk-fuelled steam engine rice mill. In the conventional husk-fuelled steam engine rice mill, mechanical energy generated by the steam engine is transmitted to the milling equipment through a belt drive power transmission. When the husk-fuelled steam engine is used for driving a grid-connected generator, mechanical energy generated by the steam engine drives the electric generator and the generated electricity is transmitted to the milling equipment and utility grid through an electric cable. A schematic diagram of the suggested system is presented in Fig. 2.

The knowledge of steam engines used in this analysis is based upon a steam engine manufactured locally in Thailand. The commonly-used steam engine in Thai rice mills is a double-acting single-cylinder steam engine. Each steam engine has two expansion stages: a high pressure and low pressure stage. Their rotational speed is limited to a maximum of 120 rpm due to a poor mechanical balancing of the dynamic mass. Most of the steam engines are horizontal arrangement engines with a sliding valve system. Lubricant is fed to the engine by mixing it with steam at an inlet valve.

System thermal efficiencies of the steam engine systems were reported in various research works. Waddle et al. [10] reported that the conversion efficiency of a 25–150 kW steam engine system fuelled by rice husk is 5%. Ramlimgam et al. [11] reported a conversion efficiency of 6% for a 30 kW steam engine fuelled by rice husk. A conversion efficiency of 7% for

Mill General Data					
Project Name	Example1		Wage Rate	200	THB/day
Mill Size	120	$\mathrm{Ton_{paddy}}$/day	Inflation rate	2	%
Life Span	15	Year			
Mill Use Factor	60	%			
Husk Data					
Husk : Paddy Ratio	22	%			
Heating Value	4000	kW-hr/ton			
Moisture Content (wet basis)	10	%			
Husk selling price	150	THB/ton			
Husk inflation rate	2	% per year			
Mill Technical Data					
Base Case (Electrical Rice Mill)					
Mill Specific Electric Demand	2.7	$\mathrm{kW/Ton_{paddy}}$/day	Investment	14449	1000 THB
Elec Consumption to process 1 $\mathrm{ton_{paddy}}$	43.07	$\mathrm{kW\text{-}hr/Ton_{paddy}}$			
Steam Engine Generator					
Capacity	236	kW	Investment	12431.55	1000 THB
Energy Conversion Efficiency	6.75	%	Maintenance Inflation Rate	2	%
Numberof extra staff	3		O&M rate	200	THB/1000 kW-hr
Electricity Price Data					
Demand Charge (include VAT 7%)	237.005	THB/kW	Exporting electricity price (include Ft and VAT 7%)	2.32404	THB/kWhr
Energy Charge (include Ft and VAT 7%)	2.262194	THB/kW-hr			
Energy Charge Inflation rate	6.17	% per year			
Calculation Result					
IRR	**23.17%**				
NPV	**16,118**	1000 THB			
Pay-Back Period	**4.88**	Year			

Fig. 1. An example of computer-based model spreadsheet.

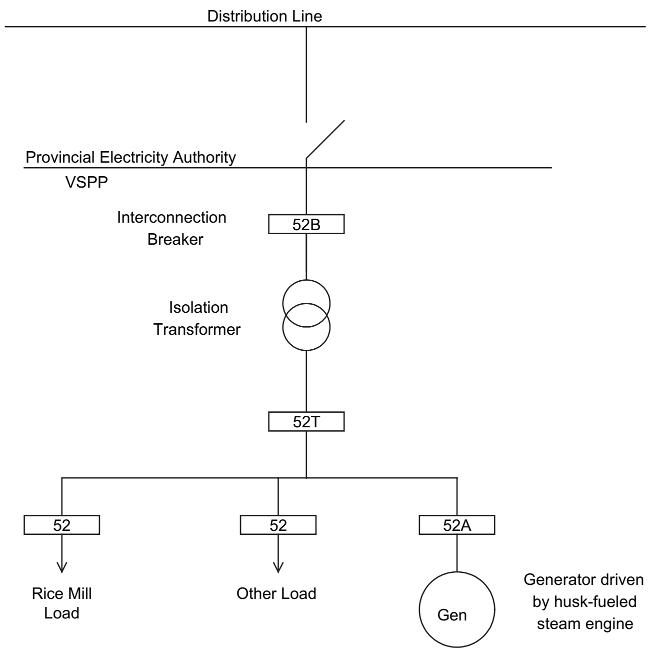

Fig. 2. Single line diagram of husk-fuelled steam engine generator rice mill.

a 100 kW steam engine fuelled by rice husk was reported by Mahin [12]. According to the literature cited, the system thermal efficiency of conventional steam engine system is assumed to be 5% in this study.

Most of the boilers used in the Thai steam engine rice mills are 3-pass fire-tube boiler with inclined step-grate furnaces. The efficiency of such boilers is very low, at around 40% as reported in [13]. In this study, the conventional low efficiency boiler has been replaced by a high-efficiency boiler, i.e., a traveling-grate stoker water-cooled furnace wall fire-tube boiler. The efficiency of the traveling-grate stoker water-cooled furnace wall fire-tube boiler is specified by the boiler manufacturer to be 60% [14]. When using the high-efficiency boiler, the thermal efficiency of the system, mentioned above can be raised from 5 to 7.5%. The technical and investment-related data of the husk-fuelled steam engine system used in this study were adopted from [4], as presented in Table 4.

The estimated investment in the electrical generator and the electrical protection follow the purchased equipment correlations and correlations for electrical work cost evaluation adopted from [15]. The estimated investments in the electric generator and electrical protection are presented in Table 5.

In order to compare the IRR of the investment in husk-fuelled steam engines as prime mover of grid-connected generators in this study and the IRR of an investment in conventional husk-fuelled rice mills, as presented in [4], the technical and economic parameters used in [4] are also used in this study. The technical and economic parameters used in this study are summarized in Table 6.

5. Results and discussion

The technical and economic parameters, presented in Tables 4 and 6, were used in the developed model presented in the previous section. The IRRs on the investment in husk-fuelled steam engines as prime mover of grid-connected generators at various sizes of rice mills from 35 to 120 t/d, as compared to the IRRs of conventional husk-fuelled steam engine rice mills are presented in Table 7. The missing IRRs indicate that the pay-back period is longer than the entire project life.

It was found that the IRRs not only depend on the mill size, but also depend on the interplay between the mill size and the steam engine generator capacity. In a particular size of rice mill, the IRRs rises with the increase of the steam engine generator capacity until the IRRs reach the maximum value and then the increasing of the steam engine generator capacity causes the decreasing of the IRR. It can be argued that the specific investment (THB kW^{-1}) in low steam engine generator capacity is higher than the value of high steam engine capacity and this causes a low IRR at a low generator capacity. However, when the steam engine capacity is too high, the necessary amount of rice husk in order to operate the steam engine generator system at high plant capacity factor is not available, and this causes the decreasing of the IRR at high generator capacity.

Please note that the purchase of additional rice husk was not allowed in this analysis. The IRRs on the investment in steam engine generators for rice mills sizes from 35 to 60 t/d reach the maximum value, when the steam engine generator capacity is 124 kW, and the IRRs on the investment in steam engine generators for rice mills sizes from 95 to 120 t/d reach the maximum value when the steam engine generator capacity is 236 kW. Those values of generator capacity can be considered as the optimum generator capacity for the husk-fuelled steam engine system.

However, the comparison of IRRs on the investment in husk-fuelled steam engines with and without a grid-connected generator shows that only the IRR on the investment in the husk-fuelled steam engine with a grid-connected generator in the largest rice mills of 120 t/d is higher than the values of the system without a grid-connected generator. This indicates that for the rice mills' sizes from 45 to 95 t/d, the conventional husk-fuelled steam engine, which generates mechanical energy for direct driving of milling equipment without generating electricity, is more appropriate than the system with grid-connected generator.

The variation of IRRs on the investment in husk-fuelled steam engines with a grid-connected generator with rice

Table 4
Technical and investment-related information of the husk-fuelled steam engine system

Piston size (in)		Storke (in)	Required steam ($t\,h^{-1}$)	Power output (kW)	Investment (THB)
High pressure stage	Low pressure stage				
7	10.5	7	0.70	47	3,457,443
8.5	12.5	8	0.84	83	3,475,337
10	15	10	1.58	124	4,343,873
12	18	12	1.89	236	4,907,186
14	21	14	2.46	375	6,099,673

Table 5
The estimated investment in electric generator and electrical protection

Steam engine power output (kW)	Generator capacity (kW)	Investment		
		Generator protection (THB)	Generator (THB)	Total (THB)
47	50	1,480,873	1,992,352	3,473,225
83	90	1,740,520	2,852,732	4,593,252
124	130	1,927,882	3,571,003	5,498,885
236	240	2,290,982	5,192,781	7,483,763
375	380	2,611,978	6,875,098	9,487,076

husk prices of rice mills size 120 t/d is presented in Fig. 3. According to the loan interest rate offered by Siam Commercial Bank on August 10, 2005, the minimum retail rate, MRR, was 6.25%. If 5% margin is set as the criteria for attractive investment, 11.25% is the minimum IRR to be classified as an attractive investment. The IRRs on the investment in the grid-connected 240 kW husk-fuelled steam engine generator for rice mills size 120 t/d are higher than 11.25%, thorough the rice husk prices range from 100 to 400 THB t^{-1}.

Table 6
Technical and economic parameters of the husk-fuelled steam engine generator system

Parameter			Unit
Rice husk			
Husk to paddy ratio	HRP	1:0.22	
Lower heating value dry basis	LHV_d	4000	$kW\,h\,t^{-1}$
Moisture content (wet basis)	MC_w	0.10	Decimal
Husk price year 0	$P_{h,0}$	150	THB t^{-1}
Specific mill electricity consumption	e_e	43.07	$kW\,h\,t^{-1}$
Husk-fuelled steam engine system			
Operation staff	ΔL	3	Person
Steam engine system energy conversion efficiency	η_{st}	0.075	Decimal
Generator efficiency	η_g	0.9	Decimal
Overall energy conversion efficiency	η_{th}	0.0675	Decimal
Operation & maintenance factor year 0	$p_{om,0}$	200	THB $kW\,h^{-1}$
Economic parameter			
Life span	N	15	Yr
Mill use factor	u	0.60	Decimal
Inflation rate	f	0.02	Decimal
Wage rate year 0	$p_{l,0}$	200	THB (man-day)$^{-1}$
Electricity			
Demand charge (include VAT 7%)	$p_{d,0}$	237.005	THB kW^{-1}
Energy charge + F_t (include VAT 7%)	$p_{e,0}$	2.2622	THB $kW\,h^{-1}$
Feed in electricity tariff + F_t (include VAT 7%)	$p_{ex,0}$	2.3240	THB $kW\,h^{-1}$
Energy charge inflation rate	f_e	0.0617	Decimal

Table 7
Comparison of IRRs on the investment in the husk-fuelled steam engine with and without grid-connected generator

Mill size (t/d)	Conventional husk-fuelled steam engine − no generator IRR (%)	Husk-fuelled steam engine with grid-connected generator	
		Gen capacity (kW)	IRR (%)
35	3.63	47	−2.65
		83	4.12
		124	3.97
		236	2.85
45	14.14	47	−4.55
		83	8.97
		124	7.40
		236	6.18
60	20.49	47	−4.55
		83	12.33
		124	11.72
		236	10.37
95	26.60	47	−4.55
		83	10.10
		124	14.59
		236	18.30
		375	15.23
120	21.15	47	−4.55
		83	10.10
		124	13.70
		236	23.17
		375	19.65

According to the sample of the contract for the purchase of power in the attachment of ‘‘Regulations for the purchase of power from very small renewable energy power producer’’, the term of contract is one-year, which is automatically renewed every year. However, it was stated in the sample of the contract that the contract can be invalid, whenever the nation energy policies are changed. Short term contract without guarantee on the policy is a source of risk in the investment. It is very interesting to find out what happens, if the VSPP program stops at a certain period before the project life span. If the VSPP program stops, the VSPPs cannot sell surplus electricity to the grid. They can only get benefit from their generators only for saving of electricity in their mills without selling of surplus electricity to the grid. Moreover, in the condition that VSPPs cannot sell surplus electricity to the grid, it is very difficult to operate their generator to cover all of their electricity consumption. It is assumed that 80% of mill electricity consumption can be covered by the electricity generation from husk-fuelled steam engine system. However, lower electricity generation also reduces the husk consumption in the mill and the fuel cost is reduced. The comparisons of effects of stopping the program at year 6 and year 11 are presented in Table 8. It was found out that the IRRs decrease significantly, if the program is stopped before the end of the project. In some cases, the IRRs are decreased from above attractive level to invest (higher than 11.25%) to lower than

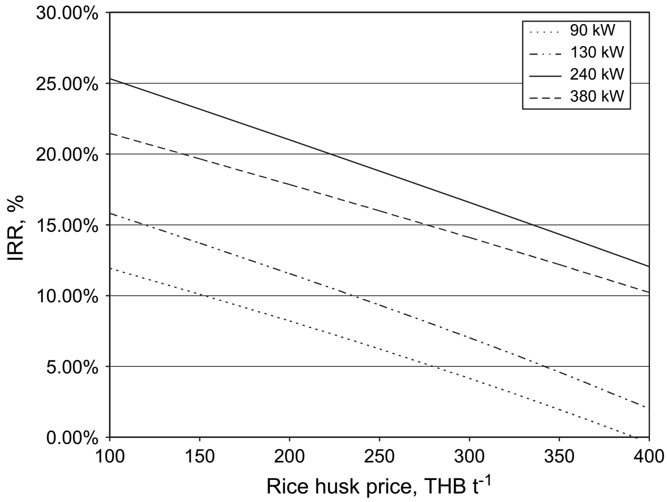

Fig. 3. Variation of IRRs on investment in husk-fuelled steam engine with grid-connected generator and rice husk price for rice mill size 120 t/d.

attractive level, which indicates the risk of non-guarantee short term contract of VSPP.

6. Conclusion

The systematic economic evaluation of the investment in the husk-fuelled steam engine grid-connected generator of the rice mill was demonstrated in this study. The IRRs on the investment in the husk-fuelled steam engine grid-connected generator for the 35–120 t/d rice mills were determined so that these five conclusions can be drawn.

1. The successful match between the rice mill size and the husk-fuelled steam engine generator capacity resulted in the highest IRRs on the investment in the husk-fuelled steam engine generator.
2. It was found that the IRRs on the investment in the steam engine generator for rice mills sizes from 35 to 60 t/d reach the maximum value when the steam engine generator capacity is 124 kW, whereas, the IRRs on the investment in the steam engine generator for rice mills sizes from 95 to 120 t/d reach the maximum value when the steam engine generator capacity is 236 kW. Those values can be considered as the best match between rice mill size and husk-fuelled steam engine generator capacity.
3. For the 120 t/d rice mill, the use of the steam engine system with the grid-connected electricity generator improves the economic performance of applying the husk-fuelled steam engine to the rice mill.
4. For rice mill sizes from 45 to 95 t/d, the IRRs of conventional husk-fuelled steam engine, which generates mechanical energy for direct driving of milling equipment without generating electricity, are higher than the steam engine system with the grid-connected electricity generator.
5. Without guaranteed long term contracts for VSPP, the risk from stopping the VSPP program before the end of the project gave very significant effects on the economic performance of applying husk-fuelled steam engines as the prime mover of grid-connected generators.

Table 8
The effects of stopping VSPP program at the year 6, year 11 and the end of project life for selected sizes of rice mill

Mill size (t/d)	Gen capacity (kW)	IRR (%)		
		Program continue until the end of project (year 16)	Program stop at year 11	Program stop at year 6
60	83	11.72	6.23	3.51
95	236	18.30	12.99	9.91
120	236	23.17	17.71	14.93

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